CHAPTER 17: BOILER WATER PREPARATION Part 2

DEMINERALIZATION BY ION EXCHANGE

Demineralization by ion exchange consists of using "resins" (similar in appearance to those used in water softeners), which are small spheres (the most common form) that have the property of exchanging ions (salts are formed by an acidic radical and an alkali radical; if they are ionizable, when dissolved in water, they can form ions of their radicals, some positive and others negative).

Resins can be classified according to their exchange mechanism:
those that exchange acid radicals (cationic resins, similar to those used in water softeners) or alkali radicals (anionic resins).

Once regenerated, the acidic (cationic) resins react with acids (containing H+, hydrogen ions) and the alkali (anionic) resins react with sodium hydroxide (NaOH), which contains hydroxide ions (OH-).

Resins that exchange alkali radicals, or cationic resins (Ca++, Mg++, Na+, K+, etc.), release an acid radical into the water by donating an H+ ion.

This acid radical is then exchanged by the alkaline or anionic resin for an OH- ion.

In short, the salts will be exchanged, forming H_2O (the union of H^+ and OH^-), that is, water.

Generally, the water must be pre-treated to remove all organic and suspended contaminants, and its chlorine content must be reduced to a very low level (less than 1 ppm).

It is usually exchanged first with the cationic resin (this eliminates alkaline radicals that can precipitate and hinder the exchange), and then the acidic radicals are exchanged in the anionic resin.

To achieve high water purity, this process must be repeated several times, or alternatively, a mixed bed can be used (a mixture of cationic and anionic resins, so that the exchange occurs alternately within the column itself on repeated occasions).

This topic offers many alternatives. But let's talk about the problems that can arise.

Anionic resin, which exchanges acidic radicals (and also exchanges silica or SiO2 as a slightly acidic radical), is highly susceptible to fouling (contamination with organic elements that reduce the resin's exchange capacity).

When anionic resin becomes contaminated, the reduced exchange capacity allows acidic radicals to pass through (resulting in a low pH in the water).

This is detected by the conductivity meter (as we saw in Part 1, this device monitors the conductivity of water, which is produced by ions or electrical charges. Since pure water is practically an insulator, this can detect the passage of salts or radicals in the treated water).

Therefore, the system is monitored and regenerated or disinfected upon detecting conductivity.

However, the problem can be more serious if silica (SiO2) is a concern for the plant, since the conductivity meter doesn't detect the presence of silica because it is almost non-ionizable (it doesn't significantly increase the conductivity of demineralized water).

If silica removal is truly desired, the anionic resin must be regenerated with the soda solution at a specific temperature—generally no higher than 50°C (122°F)—to avoid affecting the stability of the anionic resin, which is less heat-tolerant than cationic resin, some of which can withstand up to 140°C (284°F). If this temperature isn't maintained, the resin won't be properly regenerated to remove the silica.

Anionic resin generally has a volume 20% greater than cationic resin for the same exchange capacity, given its lower exchange capacity.

Although there are many types of resins, anionic resin is generally less dense than cationic resin. This allows for separation in mixed beds for regeneration (this is done with a countercurrent water flow), and they are remixed after regeneration and rinsing (they are premixed with air bubbles in the column partially filled with water).

Anionic resins are regenerated with dilute acids, with hydrochloric acid being one of the best (because there is no precipitation, but one of its problems is that if the column is made of stainless steel, it is attacked by the chloride ion).

When using other acids, such as sulfuric acid, it must be very well diluted and in low percentages, since it precipitates if it combines with some of the cations in the regeneration process if it is present at a certain concentration.

Furthermore, it must be handled with great care; it is a very dangerous acid to handle, both because of the mistake of introducing water into the acid: it almost causes an explosion due to the development of intense heat, and because if any part of the human body comes into contact with the acid, it suffers immediate ulceration that puts the person's health at risk.

Generally, sulfuric acid is cheaper than hydrochloric acid, which is why it is used in some plants (despite the risks).

If the water needs to be chlorinated for disinfection before demineralization or softening, it's advisable to remove the residual chlorine as it enters the heat exchange system.

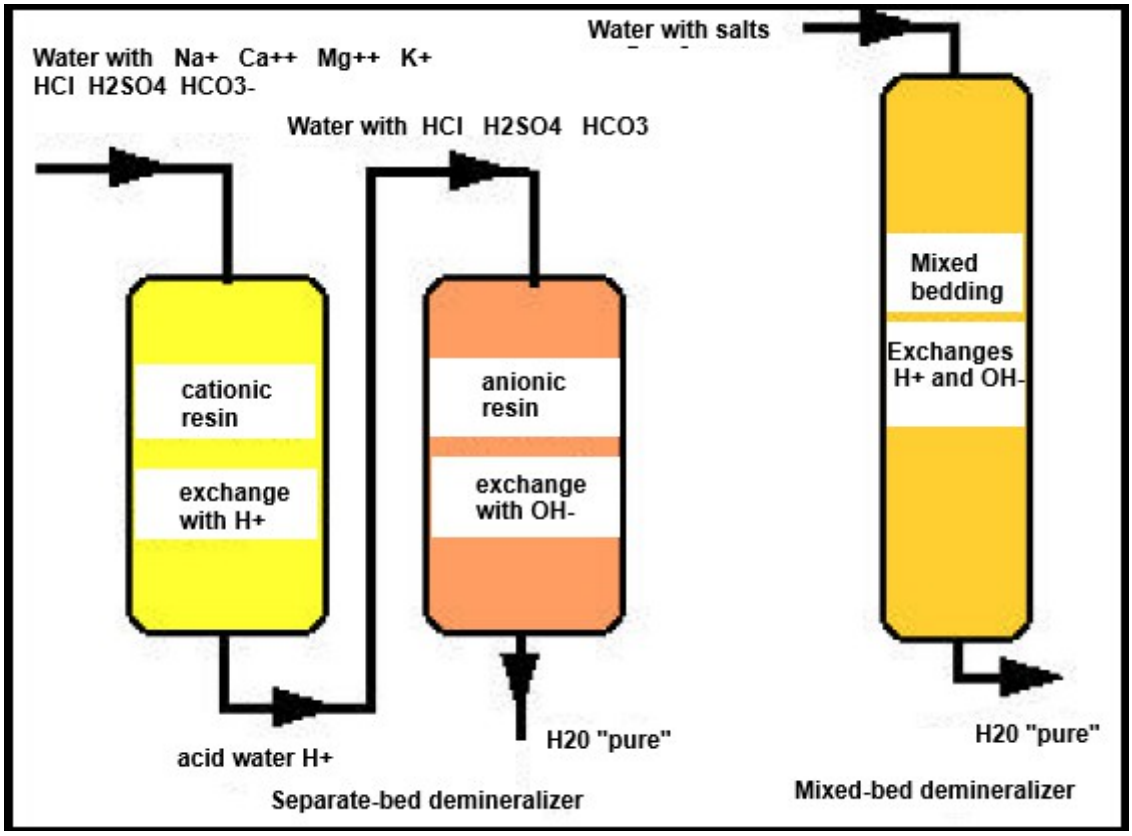
For this purpose, an activated carbon filter is installed. Activated carbon comes from various sources, but all are generally composed of carbon and have high porosity, providing a large surface area for absorbing elements such as chlorine, other gases, or organic materials.

Although there are carbons designed for other absorption functions, such as the removal of odors, tastes, colors, or the organic elements that produce them, etc.

These carbons are replaced or partially regenerated with a counter-current steam flow and vented to the atmosphere (although for greater recovery, they should be treated at high temperatures, almost to the point of calcination).

Among the various resin combinations, to achieve better exchange, a carbon dioxide (CO_2) removal tower can also be used between the cationic and anionic resins. CO_2 is produced when there is high alkalinity in the water being treated, generally well water, which is composed of acidic carbon dioxide radicals from bicarbonates.

Let's look at some simple example diagrams.



REVERSE OSMOSIS

To extract the salts contained in water (both soluble salts and those elements that are not completely soluble, such as organic compounds), there are currently methods that take advantage of the osmosis effect by applying a reverse effect, in order to obtain almost pure or demineralized water.

The effect called osmosis occurs when, in a container divided into two parts by a semipermeable organic membrane, one section contains water with salts and the other pure water, both at the same level.

We will see that the pure water tends to pass through the semipermeable membrane, causing the side with the water containing salts to rise to a certain height. This difference in height is the osmotic pressure.

But if we make the side containing the salts more pressure than the osmotic pressure (or height), we will be able to draw pure water from the salt solution into the pure water section.

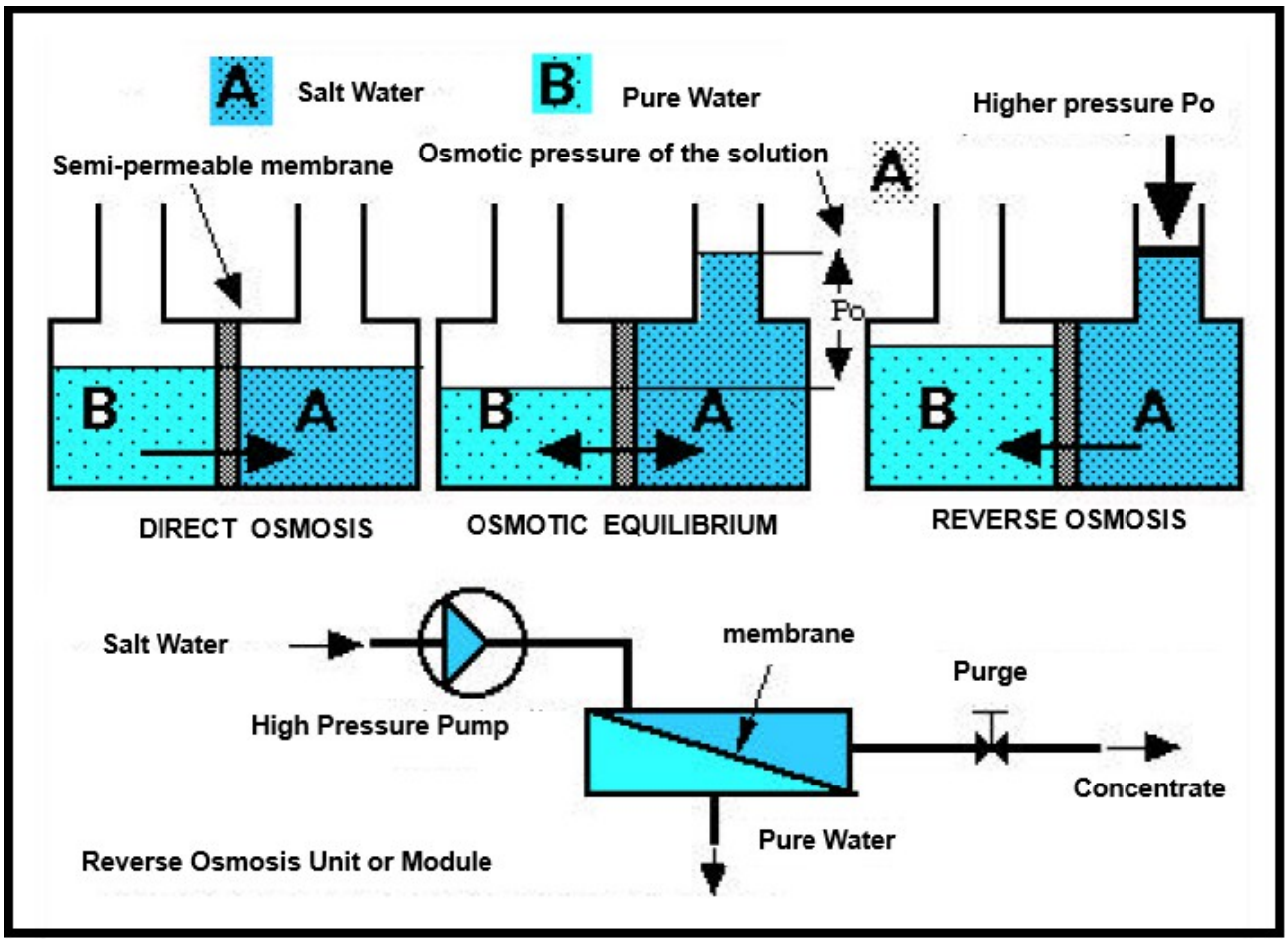
If we achieve this effect with large surface area membranes (made of cellulose acetate or polyamides, suitable for this purpose; the former have a high transfer capacity but are very sensitive), we can pump water with salts and extract a portion of that water with a lower salt concentration.

There will always be a continuous purge to maintain a limit on the salt concentration, since a higher salt concentration requires more pressure and also increases the loss of salts introduced with the clean water.

If we perform this effect in several stages, we will ensure that the "pure" water is progressively purer in each "effect" or reverse osmosis module.

The pump pressure is generally in the range of 20 k/cm² (284 PSI) to 80 k/cm² (1138 PSI).

The membranes have special shapes (spiral, tubular) and require periodic cleaning to maintain them in good condition. Their lifespan depends on the type of material and the local conditions of each system.



In some cases, the water to be treated must be prepared (due to an unsuitable pH, excessive hardness, suspended solids, disinfection, etc., or the use of antiscalant polymers in continuous dosing).

These systems have a promising future, as they can replace ion exchange, which generates significant pollution during resin regeneration (acid, soda, etc.).

These systems have proven highly useful not only in industrial applications but also in seawater purification, both on ships and in some desert regions.

The ratio between the flow rate of purified water and the feed flow rate is called conversion (expressed as a percentage).

The ions that tend to pass through most readily are those with the lowest atomic weight. Generally, sodium chloride losses are the most common, requiring more reverse osmosis passes (through membranes) to reduce these losses.

This necessitates the use of mixed resin beds at the end of the reverse osmosis chain when ultrapure water is required. This ensures sufficient water purity for use in high-pressure boilers, as well as other applications (cleaning electronic circuits, etc.).

FEEDWATER DEAERATION

Water, regardless of its source, contains dissolved gases (even demineralized water, whether from ion exchange or reverse osmosis, generally does not remove these gases, except for distilled water that exits at a temperature close to 100°C (212°F), which contains almost no gases).

Among these gases is oxygen (which makes up 21% of the atmosphere by volume, a highly corrosive element for boiler and steam systems), and its concentration must be minimized.

There are several ways to reduce it to a minimum.

One method is sequestration with a chemical (for example, sodium sulfite, hydrazine—the latter being carcinogenic and therefore not suitable for every plant, as there are other substances that can be used, though not as commonly as sulfite).

The problem with sequestration using chemicals is their cost, and in the case of sulfite, the increased amount of salts to be purged (which is why the aim should be to remove as much oxygen as possible through thermal or mechanical means, in order to use the minimum amount of sulfite).

To reduce the use of these chemical elements, we have two methods that can be used together or separately:

1- Heating the feedwater to its maximum temperature (as close as possible to 100°C (212°F) to eliminate all gases, since at atmospheric pressure, most of the oxygen will be expelled from the water.

This is seen in everyday life when you open a "hot soda"—it loses its fizz—and when you open a cold one, the carbon dioxide remains almost entirely in the liquid), or heating above 100°C (212°F) with steam purging (this causes the oxygen to be released from the water and expelled from the feed tank; this is called a deaerator).

2- The other method is creating a vacuum or decompression (which, if aided by heat, will practically eliminate the gases contained in the water).

There is a way to remove oxygen using exchange resins, a method that is not very widespread (these resins are regenerated using chemicals).

To see the influence of temperature on the oxygen content of water under atmospheric pressure, refer to the following table:

TABLE OF OXYGEN CONTENT IN WATER ACCORDING TO TEMPERATURE
(at atmospheric pressure, i.e., tank vented to the atmosphere).

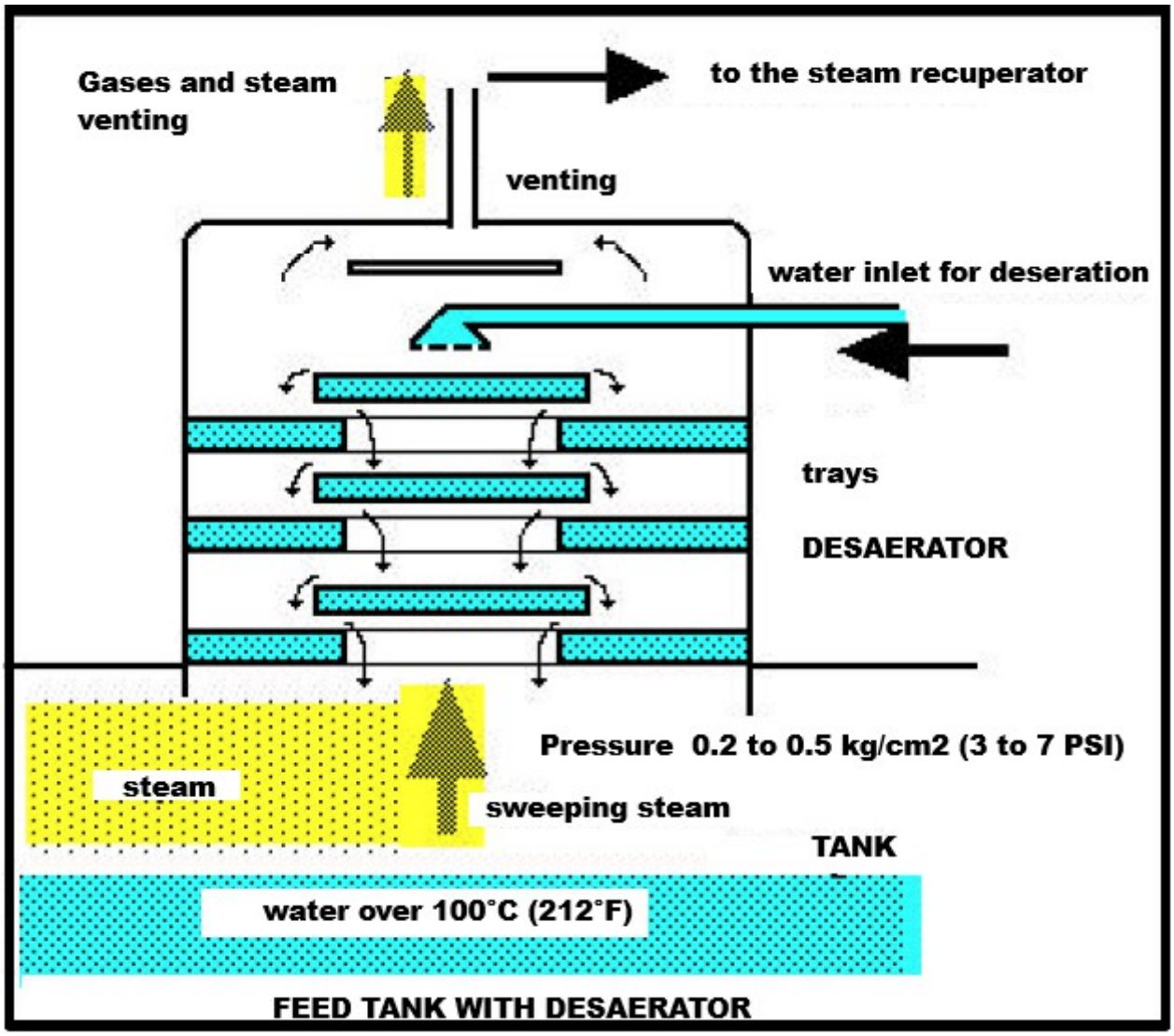
TEMPERATURE IN °C	OXYGEN CONTENT mg/kg
10ºC (50°F)	11,25
20ºC (68°F)	9,09
30ºC (86°F)	7,49
40ºC (104°F)	6,41
50ºC (122°F)	5,50
60ºC (140°F)	4,69
70ºC (158°F)	3,81
80ºC (176°F)	2,81
90ºC (194°F)	1,59
95ºC (203°F)	0,86
99ºC (210°F)	0,18

The feedwater tanks are generally open to the atmosphere (vents) and lack any gas extraction systems. In these cases, the water can be heated by steam injection, a coil, or condensate recovery, to as close to 100°C (212°F) as possible.

To achieve this, the tank must be at least 5 meters above the feedwater pump suction; otherwise, cavitation will occur (steam will form in the pump's volute, causing it to fail and requiring the feedwater to be cooled).

Remaining oxygen will be removed with chemicals (maintaining a residual level in the boiler water).

Feed tanks equipped with "deaerators" operate on the principle of heating the feed tank's makeup water in a counterflow, thus maintaining gas venting and using a small amount of "purge" steam (this steam can be recovered in a cooler or heat exchanger with the same cold makeup water, recovering both the condensate and the heat).



To keep the feed tank isolated from the atmosphere and at a temperature above 100°C (212°F), the tank must be slightly pressurized.

The steam injected countercurrently maintains a small internal pressure in the tank (the tank must have all the necessary safety features to ensure this small pressure does not exceed its value, as this could cause an accident due to tank explosion; generally, good pressure regulators are installed, in addition to relief valves and/or water-sealed columns).

These deaeration tanks must be inspected frequently, as they can develop fatigue cracks, posing a safety risk to plant personnel.

Any remaining oxygen, which is very low in this case, must also be chemically removed, leaving a residual value of the sequestering agent in the boiler water.

Feeding the boiler with cold water is bad for several reasons, from excessive consumption of oxygen scavenger to the boiler's lack of response to changes in operating conditions, apart from internal thermal shocks, which can lead to structural problems.

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